DEVELOPMENT OF MOBILE ROBOT IN VIRTUAL REALITY ENVIRONMENT FOR EDUCTIONAL PURPOSE

ABDULAZIZ SHAIF SALEH AL-GAHDARI

A thesis submitted in
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

JUNE, 2015

ABSTRACT

Pulse compression The intelligent system can help a robot to navigate through the environment by itself. The need for such system has become of essence especially when quality and accuracy is demanded in delivering complete processes of work in specific time. This project has focused on building a mobile robot that will be able to navigate and avoid collision. This thesis has aimed for developing a mobile robot in virtual reality environment for educational purposes. A robot has been developed using SolidWorks simultaneously with a suitable virtual environment. The integration of the mobile robot with the virtual reality environment has been obtained in 3D editor in Simulink Matlab. The robot has been made to move randomly in order to track different scenario possibilities. It has been found that the angular velocity from the calculation is approximately same as the one set for the simulation, which confirmed that there is no delay in the time. It has been found that the shortest and longest distance between the mobile robot and the obstacles are 11 mm and 108.7 mm for the sensor range of 85 mm and 150 mm respectively. The mobile robot has navigated through the office virtual environment and avoided collision with the obstacles.

.

ABSTRAK

Sistem pintar boleh membantu robot untuk menavigasi melalui persekitaran dengan sendirinya. Keperluan untuk sistem tersebut amat penting terutama apabila kualiti dan ketepatan diutamakan dalam melaksanakan proses lengkap aktiviti dalam masa tertentu. Projek ini memberi tumpuan kepada membangunkan robot mudah alih yang akan dapat bergerak bebas dan mengelakkan perlanggaran. Tesis ini telah bertujuan untuk membangunkan robot mudah alih dalam persekitaran realiti maya untuk tujuan pendidikan. Robot telah dibangunkan menggunakan perisian SolidWorks serentak dengan persekitaran maya yang sesuai. Integrasi robot mudah alih dengan persekitaran realiti maya telah dilaksanakan dalam editor 3D perisian Matlab Simulink. Robot dibina untuk bergerak secara rawak bagi mengesan kemungkinan terdapat senario yang berbeza. Didapati bahawa halaju sudut daripada pengiraan ini adalah kira-kira sama dengan satu set bagi simulasi, yang mengesahkan bahawa tidak ada kelewatan masa. Jarak yang terdekat dan paling jauh antara robot mudah alih dan halangan adalah 11 mm dan 108.7 mm bagi julat sensor 85 mm dan 150 mm. Robot mudah alih telah ini digerakkan melalui persekitaran pejabat maya dan perlanggaran dengan halangan-halangan telah dapat dielakkan. ..

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

DOF	Degree Of Freedom
m	Meter
Cm	Centimetre
mm	Millimetre
STL	Stereo Lithographic Cad Systems
VRML	Virtual Reality Modeling Language
WRL	World Extension format
2D	Two Dimensions
3D	Three Dimension
XML	Extensible Markup Language
CAD	Computer-Aided Design
FSM	Finite-State Machine

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Since dawn of civilization, humanity has been slowly looking for different ways to make their life easier and lessen their pain of everyday life. Through this effort human being has improved the way they do things. They invented or developed new technologies that make things faster and more accurate. Man has always found himself a way to manipulate nature in order to serve him better. Man and machine may become powerful combination. As a result for that, machine can be delivering complete processes of work in specific time with high quality and accuracy.

Many autonomous mobile robots developed for structure environments rely on guide paths either embedded into their system or painted on the floor to navigate the robot around the desired workspace [1], [2]. Such mobile robots are adequate for point-to-point tasks where the guide paths do not change over time. Many researchers have realized that mobile robots may need to navigate around their environment without the use of guide paths.

Therefore the sensors have been invented and fabricated to allow the robots to sense the environment around and based on this input sensor signal, the robot can manipulate and perform based on the surrounding environment.

Moreover, later on the Mobile robot become smarter and intelligent due to the intelligence system that provided such as an artificial intelligent, Genetic Algorithm, neural network Algorithm and fuzzy logic algorithm/controller (FLC), these systems make the robot act in fast response and stable as well. The major aim of this project is to build a mobile robot that will be able to navigate, avoid collision, by fulfilling these tasks the robot has achieved and completed the tasks that has been designed for [3].

1.2 Problem Statement

The intelligent system can help a robot to navigate through the environment by itself. It senses environment using sensor that feedback physical quantities. For instance, light, sound, distance and temperature of an object, but nonetheless it cannot comprehend the object itself like human being.

In order to build a map for indoor navigation, mobile robot must be endowed with avoid collision behaviour. This behaviour enables the robot to avoid the contour of a wall or an obstacle while applying an intelligent system.

The controller for this behaviour can be designed either using conventional control techniques or intelligent algorithms. The conventional controller requires the complete knowledge of environment for its design and will not work well in noisy and uncertain environments. This difficulty of modelling the complete environment can be overcome by employing soft computing techniques. By propose new design robot, which is flexible in term of motion in complex environment, and run this design in Virtual reality environment. In other hand, the cost and time to design and build real robot prototype and test in real world is very high compare to the robot that designed and test it in software environment.

1.3 Objectives of Project

The aim of this project is to develop of mobile robot in virtual reality environment for educational purpose. The objectives are formulated as follow:

I. To study a mobile robot in virtual environment.
II. To design a model of mobile robot in Solidworks and Simulink-MATLAB
III. To implement stateflow controller as control system for the mobile robot to void collision with the obstacles.
IV. To integrate the mobile robot design with in Virtual reality environment

1.4 The Scope of The project

The scopes of this project are:

I. Development the proposed structure of the robot and create a suitable virtual environment using SolidWorks environment.

II. Integration of the mobile robot with the virtual reality environment in 3D editor in Simulink- MATLAB

III. The diameter of the robot and wheels is 150mm and 76mm respectively

IV. The robot will move randomly inside the environment.

1.5 Research structure

I. Chapter 1 gives an overview of the project design. It covers the introduction to Mobile robot and, problem statement, objectives and the scope of work in this project.

II. Chapter 2 gives explanation on the robot, its applications, its advantages and disadvantages. This chapter also discuss the environments and how it been constructed. Finally, this chapter shows the previous studies that related to robot.

III. Chapter 3 discussed the procedure of designing the mobile robot and the environment, the procedure of creating the model in Simulink. This chapter also explains the way of implementation of virtual reality environment scene.

IV. Chapter 4 presents the results obtained from the simulation process and analyzing of the results in order to evaluate the performance of the proposed design that has been done.

V. Chapter 5 the concluding remarks for all the chapters are presented. It also contains some future research area that requires attention and further investigation.

CHAPTER 2

BRIEF REVIEW ON SIMILAR PROJECT

2.1 Introduction

Literature review is a process of collecting and analyzing data and information that are relevant to this study. The required data and information can be collected through variable sources such as journals, articles, reference books, online database and others. This chapter consists or two parts. The first part will be a case study on previous projects that relates to this project while the second part will focus on the theory aspects of this project.

2.2 Path Planning

The control system of autonomous robot generally comprises a path planner and path-tracking controller. The path error in the robot navigation primarily depends on the smoothness of the references in the planning stages. The various path planning method have been studies in previous work [4-6]. Path planning in robotics consists in the design of the best path between two given configurations. The path must avoid all obstacles present in the physical space, as well as satisfy any kinematical or dynamical defined constraint of the motion and decide the shortest path from the starting position to the target position.

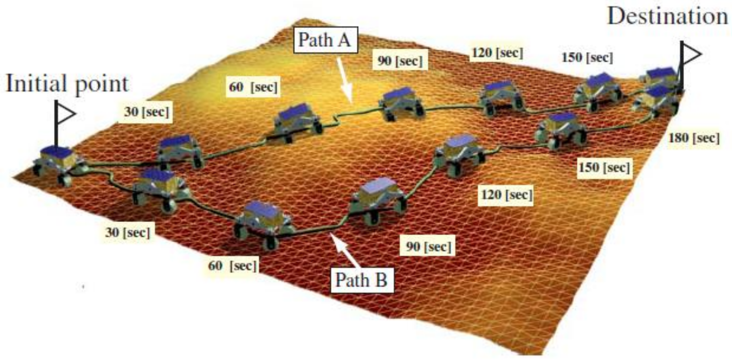


Figure 2.1: Path Planning Configuration [33]

2.3 Path Tracking

Path tracking in robotics is capabilities of the robots to follow the path that already exist with considering the motion smoothness or the dynamic constraints. Path tracking controller can be classified into four categories which is linear, non-linear, geometrical and intelligent approaches [7]. The linear approaches are computationally simple, but the path tracking motion is inconsistent with size of the path errors. To cope with the problem, several authors have proposed non-linear path tracking algorithm. Those include a path tracking method based on Lyapunov function [4, 8] and a non-linear steering control law [9] considering the driving speed. The non-linear approaches, however consider only path error convergence or system stability, but neglect the smoothness of the transient trajectory or dynamic constraints. The geometric approaches are considered as attempts to connect the path tracking to path planning. Tsugawa [10] has presented a target point following algorithm in which a cubic spline curve is used to determine the steering angle or rotational velocity of the robot. This geometric scheme show the smooth tracking motion to guide the mobile robot towards the reference path, but neglect the dynamic constraints, such as the curvature or acceleration limits which are important factors for avoiding robot or wheel slippage or stray away from the path.

2.3.1 Kinematic Constraints

In this section, the error dynamic and kinematical constraints of robot are defined. For a mobile robot driven by two differential wheels, the center of motion, denoted by C is located at the midpoint between the left and right driving wheels. Assuming that the robot moves on the planner surface without slipping, the tangential velocity and angular velocity at the center C can be written as [7].

$$v_c = \frac{r_w}{2}(w_r + w_1) \tag{2.1}$$

$$v_c = \frac{r_w}{d_w}(w_r + w_1) \tag{2.2}$$

where w_r and w_l denote the rotational velocities of the right and left driving wheels, respectively, is the radius of the wheels, and d_w is the azimuth length between the wheels. The kinematic equation of the mobile robot is given by

$$\dot{x}_c = v_{c\ \cos\theta_c} \tag{2.3}$$

$$\dot{y}_c = v_{c\ \sin\theta_c} \tag{2.4}$$

$$\theta_c = w_c \tag{2.5}$$

where coordinates (x_c ,y_c) indicate the position of the robot with respect to the world coordinate system and θ_c is the heading angle of the robot. The triplet (x_c,y_c,θ_c) is used for defining the robot posture and represented by vector P. The posture of the robot can be estimated from integration of Equations (2.3)–(2.5). The integration is implemented by the following iterative algorithm called dead reckoning.

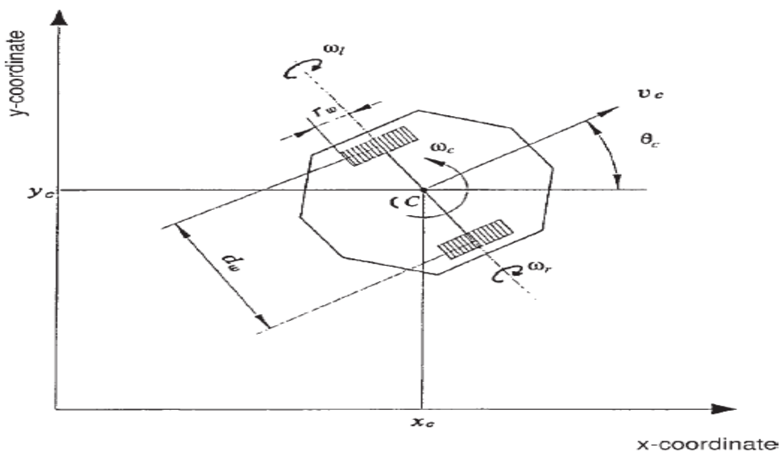


Figure 2.2: Definition of posture and velocities of two-wheeled mobile robot.

(i) In case $w_c \neq 0$

$$x_c{}^{k+1} = x_c^k + \frac{v_c}{w_c}[\sin(\theta_c^{k+1}) - \sin(\theta_c^k)] \tag{2.6}$$

$$y_c{}^{k+1} = y_c^k + \frac{v_c}{w_c}[\sin(\theta_c^{k+1}) - \sin(\theta_c^k)] \tag{2.7}$$

$$\theta_c^{k+1} = \theta_c^k + w_c\, t_s \tag{2.8}$$

(ii) In case $w_c = 0$

$$x_c{}^{k+1} = x_c^k + v_c\, t_s \cos(\theta_c^k), \tag{2.9}$$

$$x_c{}^{k+1} = x_c^k + v_c\, t_s \sin(\theta_c^k), \tag{2.10}$$

$$\theta_c^{k+1} = \theta_c^k \tag{2.11}$$

where *k* denotes the sampling index and is the sampling time

2.3.2 Dynamic Constraints

Any abrupt change in the robot motion may cause the slippage or mechanical damage to the mobile robot [7]. If the angular acceleration of each driving wheel is limited by ̇max.

$$|\dot{\mathrm{w}}_{r,1}| \leq \dot{\mathrm{w}}_{max} \tag{2.12}$$

then, from (1) and (2), the tangential and angular accelerations of the robot are bounded by

$$|a_c| + \frac{d_w}{2}|a_c| \leq r_w \dot{\mathrm{w}}_{max} \tag{2.13}$$

The above equation means that the maximum allowable bounds on tangential and angular accelerations of the robot are coupled with each other. The ranges of each value to be independently considered are obtained by taking half the value of each maximum as

$$|a_c| \leq a_{max} = \frac{r_w \dot{w}_{max}}{2} \quad (2.14)$$

$$|a_c| \leq a_{max} = \frac{r_w \dot{w}_{max}}{d_w} \quad (2.15)$$

where and are the tangential and angular acceleration limits of the robot, respectively.

2.4 Related Work

There have been several studies done before to develop the path tracking algorithm for an autonomous mobile robot. The researched that had been studied is related to this project such as the method used to tracking the path.

K.C. Koh [7]has presented that dynamic constraints of the mobile robot should be considered in the design of path tracking algorithm. The driving velocity control law has been designed based on bang-bang control and the acceleration bounds of driving wheels need to be considered. The landing curve has been introduced as it works as an intermediate path smoothly steering the rotation of the robot towards the reference path. The target-tracking algorithm used in this project is composed of two independent laws, which are steering control law and velocity control law.

Sanhyuk [11] Park has studied the new guidance logic which is able to select a reference point on the desired trajectory and lateral acceleration command was generated by using the reference point. The several guidance logic have been developed which is the proportional derivatives controller (PD) has been used on the cross-track error, has an element of anticipation for the upcoming local desired flight path, and instantaneous vehicle speed was used in the algorithm. This kinematic factor adds an adaptive capability with respect to changes in vehicle inertial speed, due to the external disturbance.

Jeff Wit [12] has presented a new path tracking technique called ‘‘vector pursuit’’. This new technique is based on the theory of screws, which was developed by Sir Robert Ball in 1900. It generated a desired vehicle-turning radius based on the vehicle’s current position and orientation relative to the position of a point ahead on the planned path and the desired orientation along the path at that point. The vector pursuit algorithm is compared to other geometrical approaches, and it is shown to be more robust, resulting in more accurate path tracking.

J. Giesbrecht [13] has presented the pure pursuit algorithm implementation and adaptation. Pure Pursuit algorithm was chosen for its accuracy, simplicity, adaptability and robustness. The Pure Pursuit algorithm was implemented in four different ways which is as a path tracker to follow the straight line between high level waypoints on a patrol mission, goal directedness has been provided to obstacle avoidance behavior, a follower vehicle to pursue a lead vehicle via GPS breadcrumbs is allowed, and as a path tracker for a detailed on-line autonomous planner. This algorithm was devised to compute the arc necessary to return a vehicle back onto a path. It computes the curvature of an arc that a vehicle must follow to bring it from its current position to some goal position, where the goal is chosen as some point along the path to be tracked and the algorithm is extremely robust to poor sensing, poor actuation, combination with other control mechanisms, and is easily adapted for changing functionality. Another adjustable parameter has been implement is the radial tolerance that assigned to each waypoint. When the radial tolerance is set too low for the vehicle, the path is overshot at the corners. With a more realistic radial tolerance, the robot does not approach the waypoint itself as closely, but is able to adhere to the path more accurately.

R. Craig Conlter [14] has studied the implementation of the Pure Pursuit Path tracking Algorithm. The pure pursuit approached a method of geometrically determining the curvature that will drive the vehicle to a chosen path point, termed the goal point. The method itself is straightforward. The only real implementation problems lie in deciding how to deal with the path information (communication, graphics, updating the path with new information from the planner). There is one parameter in the pure pursuit algorithm, which is a look ahead distance. The effects of changing the look ahead distance must be considered within the problem faced such as regaining the path and maintaining the path.

Tao Dong [15] has presented path tracking and obstacle avoiding based on fuzzy logic approached. Fuzzy logic control algorithms are developed to achieve close path tracking while avoiding obstacles. The Fuzzy Logic Controller is activated when the obstacle sensor detects any obstacle. UAV velocity and heading angle change into corresponding different situations will be generated by the FLC. A twolayered FLC was used to make the UAV track its path while avoiding the fixed, but unexpected obstacles.

Jean-Matthieu bourgeot [16] has presented the path planner designed. It contains of two parts which is the references path need to be determined and tracking algorithm was applied which the robot followed the reference track. Using A has developed a 3D path planning method* algorithm to find the easiest track biped robot, then the low-level path tracking followed the path. For the path tracking strategy, heading and literal offset has been measured in the path tracking assignment.

G. Ambrosino [17] has studied the path generation and tracking algorithm for 3D UAV. The 3D path has been obtained by using Dubins Algorithm. Straight lines and circles/arcs of constant radii compose one of the characteristic of the path generated by the proposed algorithm. The line-of-sight guidance algorithm has been used for path tracking algorithm. This algorithm is based only on the kinematic equations of motion. The algorithm for the path tracking guarantees, under specified assumptions the tracking error, both in position and in attitude, asymptotically tends to zero.

Jacky Baltes [18] has presented the used of reinforcement learning in solving the path-tracking problem for car-like robots. The most important concept in reinforcement learning is the agent and environment. In the path-tracking problem, the reward is based on how well the agent tracked the given path. Reinforcement learning can be adapted to control a car in path tracking. The controller is needed to keeps the car on the track. The reinforcement controller is the only controller that has been used successfully to drive cars with and without linear steering behavior.

Takeshi Yamasaki [19] has studied about a guidance and control system for a trajectory-tracking unmanned aerial vehicle (UAV). A proportional navigation guidance law is applied to a trajectory-tracking flight to achieve the robust trajectory-tracking guidance and control system. The system employed a dynamic inversion technique for the guidance force generation, which allows the UAV to maintain high maneuverability, and a simple velocity control to obtain a desired velocity. With the proportional navigation guidance, UAV may avoid its control saturation or divergence even in large tracking-error situations.

Guangfeng Yuan [9, 20] has developed tracking control approach for a car-like robot based on back stepping techniques and a neural dynamics model. The proposed control algorithm can generate smooth and reasonable velocity commands and deal with arbitrarily large tracking error. The advantage using back stepping is simple and stable. While the disadvantage is has a speed jump that has caused huge acceleration. The tracking control model can produced a smoothly changing velocity curve with time. The stability of the control systems are analyzed and proved using a Lyapunov stability theory.

A.Hemami [9] has proposed a new control strategy to determine the steering angle at each instant based on measured errors, the offset from the path and the deviation in orientation. The steering system is considered to control the angle of the steering wheel so that any deviation from the path is corrected in a stable manner and as fast as possible, and without oscillations about the path. Besides that, the dynamic equation of the vehicle is formulated to study the effect of a control strategy.

André KAGMA [21] has presented a method to track straight lines path with a car-like tricycle vehicle. Straight line tracking controller is used as a control strategy to track the path, as a robot is moves. The aim of this project is to design a controller which makes the vehicle follow the X – axis. Kinematics of the tricycle robot has been considered in this project.

The authors [27] have studied formation control of nonholonomic mobile robots considering obstacle avoidance. In addition, they have proposed potential functions of the distance between the real mobile robots and obstacles. There were two difficulties for the formation control in the presence of obstacles in the field. Firstly, the drawback of the virtual structure approach is that a real mobile robot may not be able to avoid an obstacle, even if the corresponding virtual robot can avoid it. Secondly, it may be difficult to maintain the desired formation depending on the location of obstacles. In this case, a new formation control method has been proposed which takes trade-off between the formation maintenance and the obstacle avoidance using a potential function of the distance between each mobile robot and obstacles. A numerical simulation has been conducted to verify the effectiveness of the proposed method over MATLAB/Simulink.

Pandey, A& Parhi, D. R. [28] have presented a path-planning system that can control and safely navigate mobile robot motion in a static environment. In addition, the authors have proposed Mamdani fuzzy logic navigation with knowledge base minimum rules that drive the mobile robot from a known starting position, regardless of the known or unknown scenarios with hurdles in cluttered environments. This method has three in puts hurdle distances obtained from left, right and front sensors and the output is single heading angle, which control the movement of mobile robot. This proposed method can be applied for mobile robot in different environments.

The authors [29] have present the use of virtual reality techniques in a robotics framework, Virtual Reality Engine provides realistic visualization of large offshore scene models in an immersive environment, by using this technique, the Immersive virtual environment reduces risks and costs of real operation tests scenarios.

The authors in [30] have proposed teleoperation systems for remote control of robot and the use of 3D virtual reality. The study has focused on the implementation and evaluation of the navigation of mobile robot integrated in telerobotics systems, which include the concept of 3D virtual reality. The authors have developed a mobile robot behavior in ASSET tool and validated simulation step using Fuzzy Logic Controllers (FLC).

The authors [31] proposed based on MATLAB / Stateflow two-wheeled robot dance behavior analysis steps, this study has focused on FSM (Finite State Machine) theory as the foundation, based on the MATLAB / Stateflow graphical behaviour description method. Stateflow is a graphical language, simple and easy to understand, the modeling and programming process together, with visualization.

The authors [32] have presented an experimental implementation of a hierarchical control, which is performed along with the artificial potential field method in carrying out the obstacle avoidance task with the wheeled mobile robot (WMR). The work aimed at helping students integrate theoretical and practical knowledge with a relevant and modern open-architecture testbed that allows rapid prototyping. Simulations were carried out using Matlab-Simulink. On the other hand, Matlab-Simulink, Control Desk, and the DS1104 electronic board (dSPACE) are employed for the real-time experiments since the graphical environment provided by Simulink facilitates the analysis, design, and construction of dynamic systems.

.

Table 2.1: list of Related Works and Project Description

Project Title	Year	Author	Project Description
A New Control Strategy for Tracking in Mobile Robots and AGV's	1990	A. Hemami, M.G. Mehrabi, and R.M.H. Cheng Department of Mechanical Engineering Concordia University, Canada	Proposed a new control strategy that considers steering system. Formulated dynamic equation of the vehicle.
A Simple Path Tracking Controller For Car-Like Mobile Robots	1997	André Kamga and Ahmed Rachid System automatic Laboratory France	Design and used straight line tracking controlleras a control strategy to track the path-Consider kinematic of the tricycle robot.
Path-tracking Control of-Non-holonomic Car-like Robot With Reinforcement Learning	2000	Jacky Baltes and Yuming Lin Centre for image Technology and Robotics University of Auckland, Auckland New Zealand.	Used reinforcement Learning and Reinforcement Controller.
Autonomous Ground Vehicle Path Tracking	2000	Jeffrey S. Wit University of Florida	Used vector pursuit tracking technique.
Tracking Control of a Mobile Robot Using Neural	2001	Guanfeng Yuan The Faculty of Graduate Studies of The University	Used back stepping techniques and a neural dynamics model. - The stability of the control
Path Planning And Tracking in a 3D Complex Environment for an Anthropomorphic	2002	Jean – Matthieu Bourgeot, Nathalie Cislo, Bernand INRIA Rhone-Alpes, BIP Project, Montbonnot	3D path planning method develop by using A*algorithm- Path tracking strategy measure heading and literal offset
Path Tracking for Unmanned Ground Vehicle Navigation	2005	J. Giesbrecht, D. Mackay, J. Collier, S. Verret DRDC Suffield Defence Research and Development	Used pure pursuit algorithm. Implement the radial tolerance waypoints.
Algorithms for 3D UAV Path Generation and Tracking	2006	G. Ambrosino, M. Ariola, U. Ciniglio, F. Corraro, A. Pironti and M. Virgilio	Used Dubins Algorithm for 3D Path-Used line-of-sight guidance algorithm for tracking path.
Robust Trajectory-Tracking Method for	2007	Takeshi Yamasaki, Hirotoshi Sakaida, Keisuke Enomoto,	Used proportional navigation guidance law. -

UAV Guidance Using Proportional Navigation		Hiroyuki Takano and Yoriaki Baba Department of Aerospace Engineering, National Defense	Employed a dynamic inversion technique for the guidance force generation.
Dancing behavior modeling and logic control simulation of two_wheeled robot based on Stateflow	2012	Yu, J., Yang, Q., Sun, L., & Wang, G	Used MATLAB / Stateflow based on finite state machine to as a controller for the wheeled robot
Remote control of mobile robot through 3D virtual reality environment	2013	Baklouti, E., Jallouli, M., Amouri, L., & Amor, N. B	Used concept of 3D virtual reality for controlling mobile robot using using Fuzzy Logic Controllers
Virtual reality techniques for planning the offshore robotizing	2014	Carvalho, F., Raposo, A., Santos, I., & Galassi, M	Used virtual reality techniques in a robotics framework, Virtual Reality Engine
MATLAB Simulation for Mobile Robot Navigation with Hurdles in Cluttered Environment Using Minimum Rule based Fuzzy Logic Controller	2014	Pandey, A., & Parhi, D. R.	Used a path-planning system with Mamdani fuzzy logic navigation with knowledge.
Obstacle avoidance task for a wheeled mobile robot—a Matlab-Simulink-based didactic application.	2014	Silva-Ortigoza, R., Márquez-Sánchez, C., Carrizosa-Corral, F., Hernández-Guzmán, V. M., García-Sánchez, J. R., Taud, H., ... & Álvarez-Cedillo, J. A.	Used artificial potential field method in carrying out the obstacle avoidance task with the wheeled mobile robot
Formation control of mobile robots with obstacle avoidance	2014	Miyazaki, T., & Takaba, K	Used a potential functions of the distance between the real mobile robots and obstacles using Matlab/Simulink

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses several steps need to be taken in conducting this project. Design procedures and software used are all discussed in this chapter. The flow chart represents guideline for procedures and steps for this project. It has explained the details about the SolidWorks, MATLAB and 3D editor software that have been used.

3.2 Project Flow chart

The flow chart provides description of specific relationships and linkages represented in flow within the research process. It can also be used as a framework to help the researcher to focus on the right direction. The following section briefly explains the stages involved in the framework as presented below.

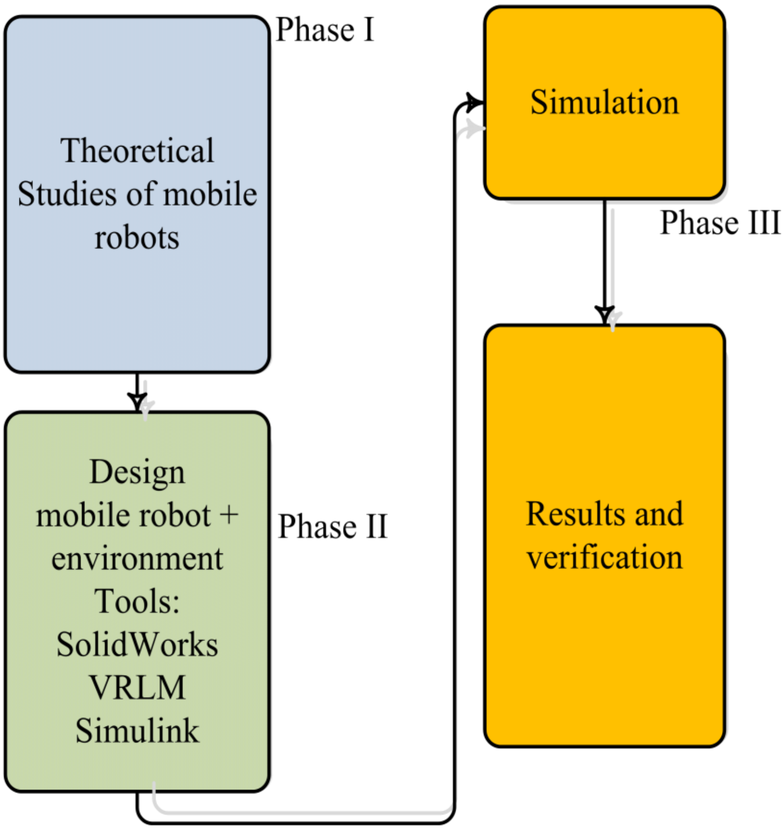


Figure 3.1: Project Flowchart

3.3 Design of the Mobile Robot and The Environment Using SolidWork

SolidWorks is Computer-Aided Design (CAD) software that offers tools to create, simulate manage and publish a 3D design. The powerful tools let the designer to visualize and simulate the design before the manufacturing process take place. SolidWorks is very popular due to its friendly usage and its several applications such as academic, research and development purposes also, in the industrial production for designing heavy-duty tools. One of the advantages of using SolidWorks is that it has powerful simMechanics-link tools that can convert the Solidworks model to Simulink blocks [22].

3.3.1 Phase of the Mobile Robot Design

This section is discussing about the steps and procedures of designing the mobile robot starting by designing each part separately and finally assembling it to create the integrated mobile robot. Figure 3.2 explains the steps for designing SolidWorks model.

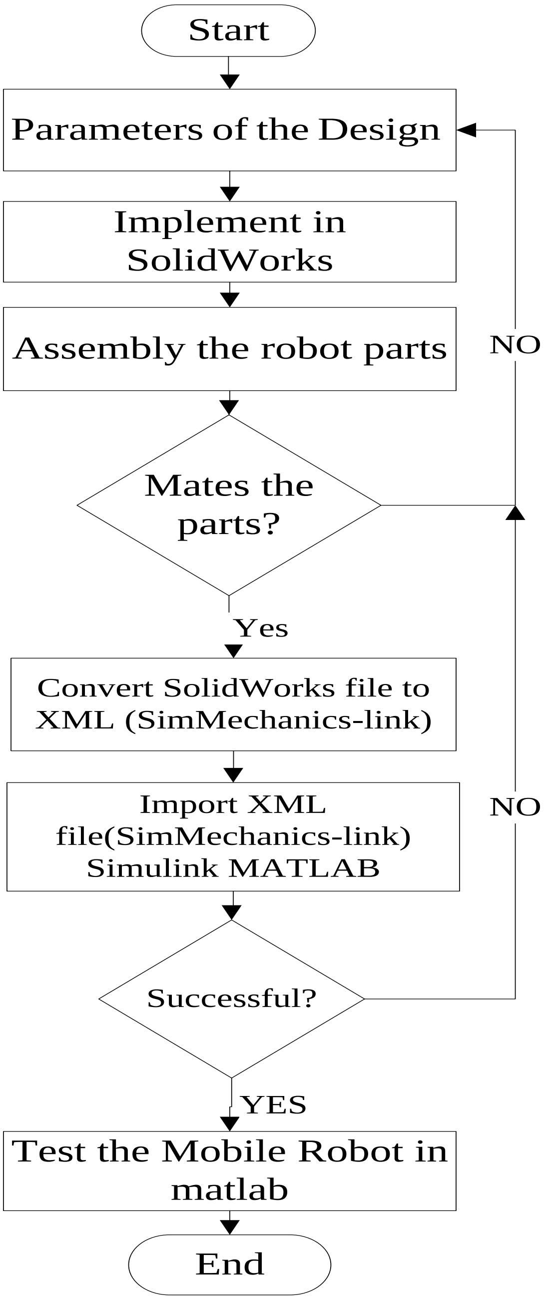


Figure 3.2 Flowchart of designing the Mobile Robot

3.3.1.2 Design the Body

The design of the robot takes the cylindrical shape in order to rotate inside the environment smoothly and without any collision with obstacles, unlike other shapes such as square shape which has four corners that might hit any corner during the motion. Figure 3.3 shows the structural of the body design.

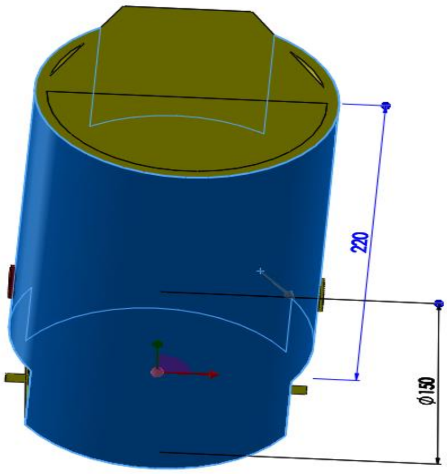


Figure 3.3: Front View For of the Proposed Design

The wheel's house has been trimmed out from the cylindrical shape (body's base) in order to make the robot works as integrated unit, when the mobile robot moves and rotates the wheels will not hit the obstacles.

3.3.1.3 Caster Mount

This works as stand that connects between the base of the robot and caster wheel, this part has significant task which provides one degree of freedom (1DOF) for free rotation in 360° degree clock wise or counter clockwise with respect the robot frame, due to its presence, the mobile robot can turn to the left or to the right smoothly. Figure 3.4 shows the caster mount part.

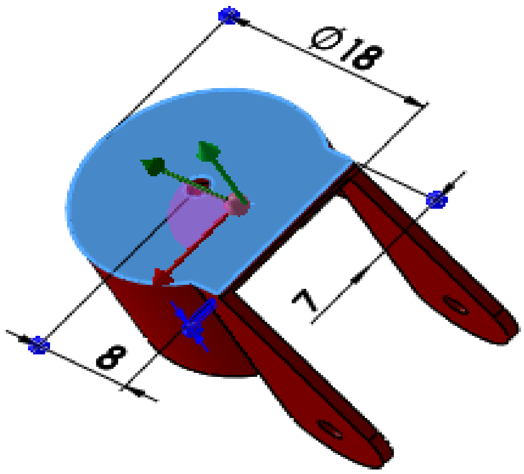


Figure 3.4: Caster Mount

3.3.1.4 Caster Wheel

This part is separately designed and attached to the robot's base by the caster mount in order to move freely and balanced during its motion. This free wheel rotation provides one degree of freedom (1DOF). Both caster mount and caster wheel provides (2DOF) which can minimize the number of blocks in Simulink after extracting from SolidWorks, and for making the simplicity of the system. The more the degree of freedom, the more extracting blocks in Simulink and the more complex the system to be controlled. Figure 3.5 shows caster wheel during design in SolidWorks.

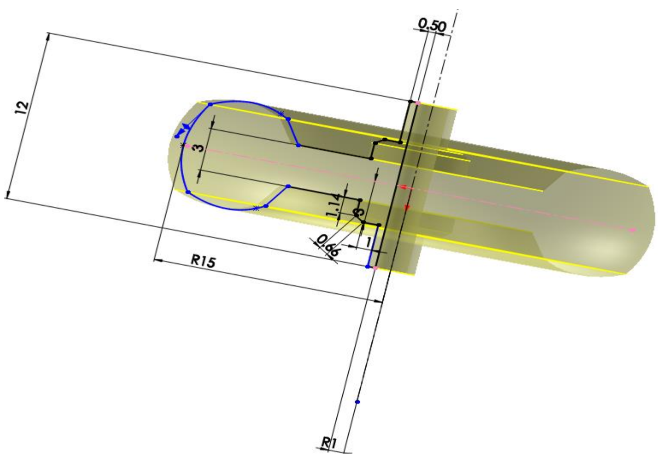


Figure 3.5: Caster Wheel

3.3.1.5 Wheels

The left and right wheels are fit and mount on the left and right side of the robot respectively, the dimension of wheels are 38 mm radius, 7 mm thickness and 2.5 mm inner radius as illustrated in Figure 3.6. The distance between left and right of wheel's house is shorter than the diameter of robot. When the robot moves and rotates, the wheels will not take extra space of the rotation. These wheels will be control by the controller which will be discuss in later topic.

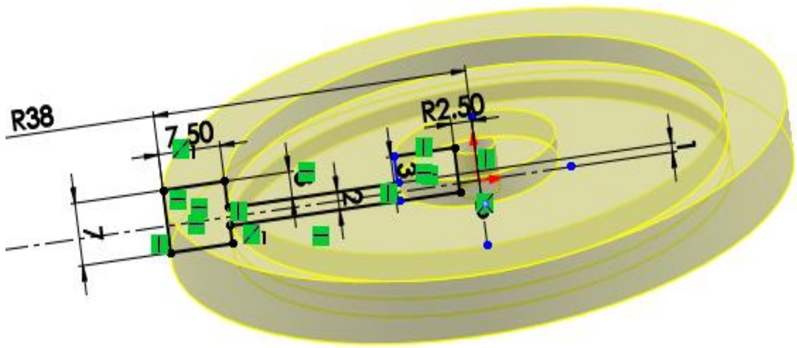


Figure 3.6: The Mobile Robot Wheels

3.3.1.6 Assembly phase

After designing phase is completed separately for each part, the next phase is to assemble all these parts together in order to create the final robot's model. The tool used in assembling all these parts together is Mate-Toolbox in SolidWorks, each mate has different representation that can be converted in Simulink block, such as mating the robot's body with wheels using concentric and coincident mate, which will convert to revolute and wheel rigid blocks respectively. Revolute block provides one degree of freedom (1DOF) and the motion for the wheel to move with respect to the body frame. Figure 3.7 shows the type of mates that used to connect and assemble the body with wheels and caster mount with caster wheel in SolidWorks.

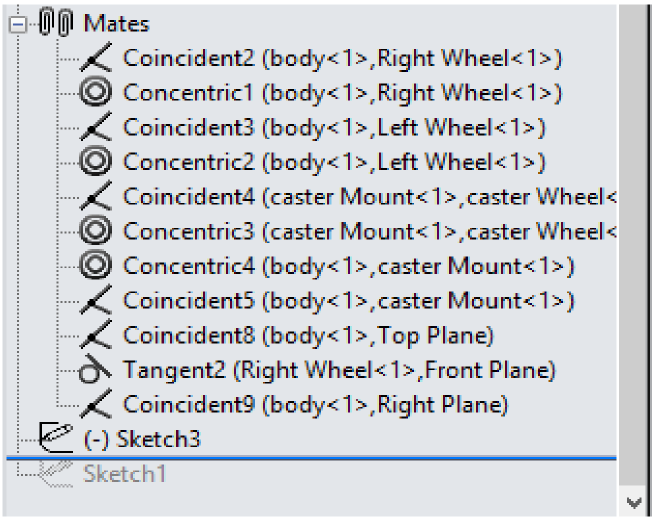


Figure 3.7: Mate used in Assembly phase

Figure 3.8 shows the mobile robot during the assembly phase where each part is located near its fixed position.

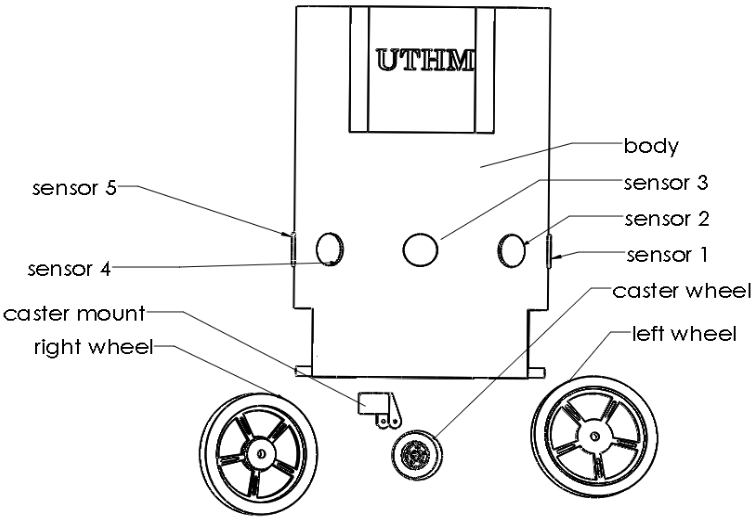


Figure 3.8: Explore View of the Robot in Solid Works

3.3.1.7 Summary of Dimension of Mobile Robot

Table 3.1 shows all the parameters discussed above, which were utilized during the designing phase. The dimensions of all the parts will be explained in details and attached in the appendix B

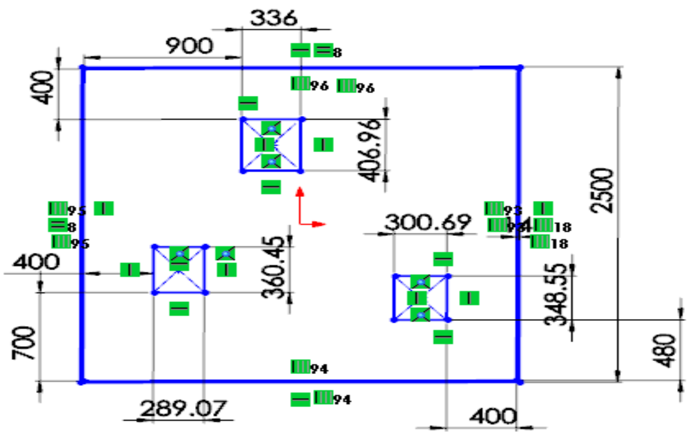
Table 3.1 Mobile Robot Parameters

Part	Dimension (mm)		
	Radius	**Thickness**	**Height**
body's robot	75	6	220
wheel	38	7	7.5
Caster clamp	18	3	20
Caster wheel	15	7	12

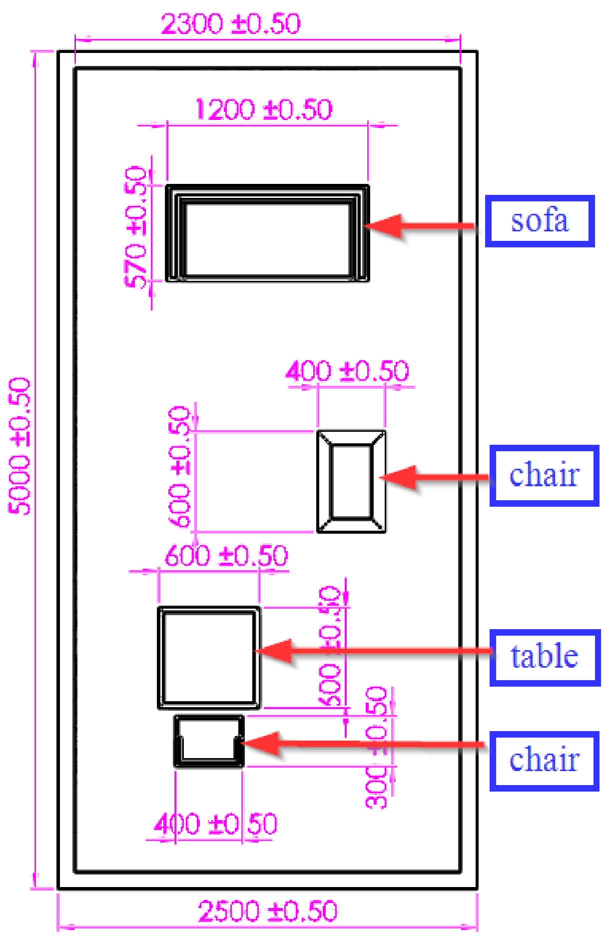
3.3.2 Designing the Environment in Solid Works

The environment in robotics is the workspace designed for the robot to work within in order to archive different task. In this work, it has been designed for two different environments, and each environment has different dimension of length and width as well as the position of the obstacles. First environment is about model of room with dimension of 2500 mm×2500 mm containing of three small chairs.

However, the second environment is model of an office environment, which is more complex than the room environment in terms of the dimension, number of the obstacles and is more realistic to the real world. The office environment consists of an office table, chair, sofa and small chair. The dimension is 5000 mm×2500 mm, the wall thickness is 14 mm for the room environment and 100 mm for the office environment as shown in Figure 3.9 (a) and (b) show the dimension of the environments and the obstacles.



(a)



(b)

Figure 3.9: Sketch of the Environments (a) Room and (b) Office.

REFERENCES

1. Siegwart, R. and I.R. Nourbakhsh, Autonomous mobile robots. Massachusetts Institute of Technology, 2004.
2. Mattaboni, P.J., Autonomous mobile robot, 1996, Google Patents.
3. Ng, K.C. and M.M. Trivedi, A neuro-fuzzy controller for mobile robot navigation and multirobot convoying. Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on, 1998. 28(6): p. 829-840.
4. Kanayama, Y., et al. A stable tracking control method for an autonomous mobile robot. in Robotics and Automation, 1990. Proceedings., 1990 IEEE International Conference on. 1990. IEEE.
5. Elnagar, A., & Basu, A. (1994). Piecewise smooth and safe trajectory planning.*Robotica*, *12*(04), 299-307..
6. Tounsi, M. and J. Le Corre, Trajectory generation for mobile robots. Mathematics and computers in simulation, 1996. 41(3): p. 367-376.
7. Koh, K.C. and H.S. Cho, A smooth path tracking algorithm for wheeled mobile robots with dynamic constraints. Journal of Intelligent and Robotic Systems, 1999. 24(4): p. 367-385.
8. Hemami, A., M. Mehrabi, and R. Cheng, Synthesis of an optimal control law for path tracking in mobile robots. Automatica, 1992. 28(2): p. 383-387.
9. Hemami, A., M. Mehrabi, and R. Cheng. A new control strategy for tracking in mobile robots and AGVs. in Robotics and Automation, 1990. Proceedings., 1990 IEEE International Conference on. 1990. IEEE.
10. Tsugawa, S. Steering control algorithm for autonomous vehicle. in Proc. of the Japan-USA Symposium on Flexible Automation. 1990.

11. Park, S., J. Deyst, and J.P. How. A new nonlinear guidance logic for trajectory tracking. in Proceedings of the AIAA Guidance, Navigation and Control Conference. 2004.
12. Wit, J., C.D. Crane, and D. Armstrong, Autonomous ground vehicle path tracking. Journal of Robotic Systems, 2004. 21(8): p. 439-449.
13. Giesbrecht, J., et al., Path tracking for unmanned ground vehicle navigation. DRDC Suffield TM, 2005. 224.
14. Coulter, R.C., Implementation of the pure pursuit path tracking algorithm, 1992, DTIC Document.
15. Dong, T., et al. Path tracking and obstacles avoidance of uavs-fuzzy logic approach. in Fuzzy Systems, 2005. FUZZ'05. The 14th IEEE International Conference on. 2005. IEEE.
16. Bourgeot, J.-M., N. Cislo, and B. Espiau. Path-planning and tracking in a 3D complex environment for an anthropomorphic biped robot. in Intelligent Robots and Systems, 2002. IEEE/RSJ International Conference on. 2002. IEEE.
17. Ambrosino, G., et al. Algorithms for 3D UAV path generation and tracking. in Decision and Control, 2006 45th IEEE Conference on. 2006. IEEE.
18. Baltes, J. and Y. Lin, Path tracking control of non-holonomic car-like robot with reinforcement learning, in RoboCup-99: Robot Soccer World Cup III. 2000, Springer. p. 162-173.
19. Yamasaki, T., et al. Robust trajectory-tracking method for UAV guidance using proportional navigation. in Control, Automation and Systems, 2007. ICCAS'07. International Conference on. 2007. IEEE.
20. Yuan, G., Tracking control of a mobile robot using neural dynamics based approaches. 2001: National Library of Canada= Bibliothèque nationale du Canada.
21. KAMAGA, A. and A. Rachid, A simple path tracking controller for car-like mobile robots. choice, 1997. 1: p. 2.
22. Li, Y., et al. SolidWorks/SimMechanics-Based Lower Extremity Exoskeleton Modeling Procedure for Rehabilitation. in World Congress on Medical Physics and Biomedical Engineering May 26-31, 2012, Beijing, China. 2013. Springer.

23. Khaled, N., Virtual Reality and Animation for MATLAB® and Simulink® Users: Visualization of Dynamic Models and Control Simulations. 2012: Springer Science & Business Media.

24. Dong, Z., et al. Real-time voxelization for complex polygonal models. in Computer Graphics and Applications, 2004. PG 2004. Proceedings. 12th Pacific Conference on. 2004. IEEE.

25. Patil, S. and B. Ravi. Voxel-based representation, display and thickness analysis of intricate shapes. in Computer Aided Design and Computer Graphics, 2005. Ninth International Conference on. 2005. IEEE.

26. Man, Z., Robotics. 2005: Pearson/Prentice Hall.

27. Miyazaki, T., & Takaba, K. (2014, October). Formation control of mobile robots with obstacle avoidance. In Control, Automation and Systems (ICCAS), 2014 14th International Conference on (pp. 121-126). IEEE.

28. Pandey, A., & Parhi, D. R. (2014). MATLAB Simulation for Mobile Robot Navigation with Hurdles in Cluttered Environment Using Minimum Rule based Fuzzy Logic Controller. Procedia Technology, 14, 28-34.

29. Carvalho, F., Raposo, A., Santos, I., & Galassi, M. (2014, July). Virtual reality techniques for planning the offshore robotizing. In Industrial Informatics (INDIN), 2014 12th IEEE International Conference on (pp. 353-358). IEEE.

30. Baklouti, E., Jallouli, M., Amouri, L., & Amor, N. B. (2013, December). Remote control of mobile robot through 3D virtual reality environment. In 2013 International Conference on Individual and Collective Behaviors in Robotics (ICBR).

31. Yu, J., Yang, Q., Sun, L., & Wang, G. (2012, July). Dancing behavior modeling and logic control simulation of two_wheeled robot based on Stateflow. InIntelligent Control and Automation (WCICA), 2012 10th World Congress on (pp. 89-92). IEEE.

32. Silva-Ortigoza, R., Márquez-Sánchez, C., Carrizosa-Corral, F., Hernández-Guzmán, V. M., García-Sánchez, J. R., Taud, H., ... & Álvarez-Cedillo, J. A. (2014). Obstacle avoidance task for a wheeled mobile robot—a Matlab-Simulink-based didactic application. MATLAB: Applications for the Practical

Engineer, 79-102.

33. Ishigami, G., Nagatani, K., & Yoshida, K. (2007, April). Path planning for planetary exploration rovers and its evaluation based on wheel slip dynamics. In *Robotics and Automation, 2007 IEEE International Conference on* (pp. 2361-2366). IEEE.